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Workshop Proceedings

Low-Cost Wastewater Treatment Systems for Communities and Municipalities

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A REVIEW OF AQUACULTURE WASTEWATER TREATMENT SYSTEMS

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INTRODUCTION

Aquaculture wastewater treatment processes utilizing vascular aquatic plants have been investigated in the United States since early 1948. The early studies concentrated on the use of floating plants such as the water hyacinth *(Echhornia crassipes)* and duckweed *(Lemna* sp., *Spirodela* sp. and *Wolffia* sp.). More recent research has concentrated on the use of rooted aquatic plants such as reeds *(Phragmites communis)* and bulrush *(Schoenoplectus lacustris)*. The latest research presently being conducted by NASA at the National Space Technology Laboratories (NSTL) in Mississippi involves combining high surface area microbial filter systems with rooted plants such as the common reed *(Phragmites communis)* to produce a hybrid wastewater treatment process with more versatility. This process can be used to treat high concentrations of hazardous and toxic chemicals. It has also demonstrated potential in minimizing odor problems when used for treating effluent from anaerobic systems. This process is capable of operating in cold climates and can tolerate higher salt concentrations in wastewater than water hyacinths.

An astounding growth in the number and extent of research projects involving the water hyacinth has occured in recent years, corresponding with the spread of this plant to all parts of the world with climates favorable to its growth (1-23). A review was published by Pieterse which covered all aspects of water hyacinth research that had been accomplished up to 1978 (8).

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WATER HYACINTH SYSTEMS

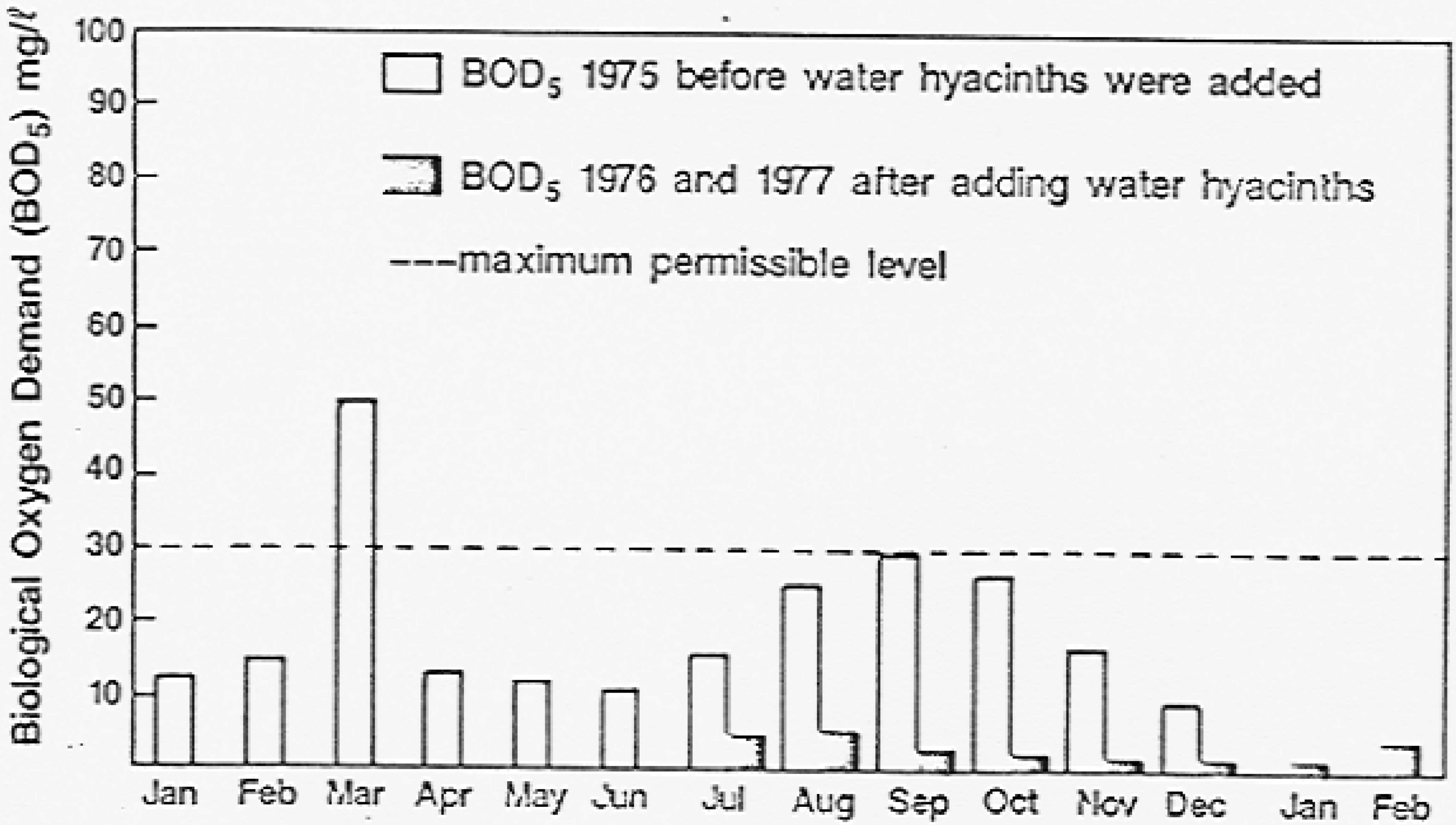
The first operational water hyacinth wastewater treatment system was installed at NSTL in 1976 and has been functioning very effectively for the past eight years (22). This system consists of a single cell lagoon with a surface area of 2.02 ha (5 acres) and an average depth of 1.22 m (4 ft.). The average flow rate was 473 m^3/d (125,000 gal/d) in 1976 and approximately 606 m^3/d (160,000 gal/d) in 1984. The BOD_5 loading rate in 1976 averaged 24.6 kg/ha/d (22 lbs/ac/d) and has increased to approximately 31.4 kg/ha/d (28 lbs/ac/d) today. Data in Figures 1 and 2 demonstrate the year round effectiveness of this system in maintaining effluent secondary treatment levels of 30 mg/ℓ or less, BOD_5 and TSS. The efficiencies of three different harvesters were also evaluated and the data shown in Table 1.

The first operational water hyacinth system for treating photographic and laboratory chemical wastewater was installed at NSTL in 1975 (17). Although this system has been very effective in treating chemical wastewater during the past nine years, it is programmed to be upgraded with a hybrid microbial filter/reed system within the next five years due to increased growth and wastewater volumes at NSTL.

In June 1975, NSTL entered into a joint experimental program with Orange Grove, a community in North Gulfport, Mississippi, to evaluate the use of water hyacinths to upgrade an aerated lagoon system.

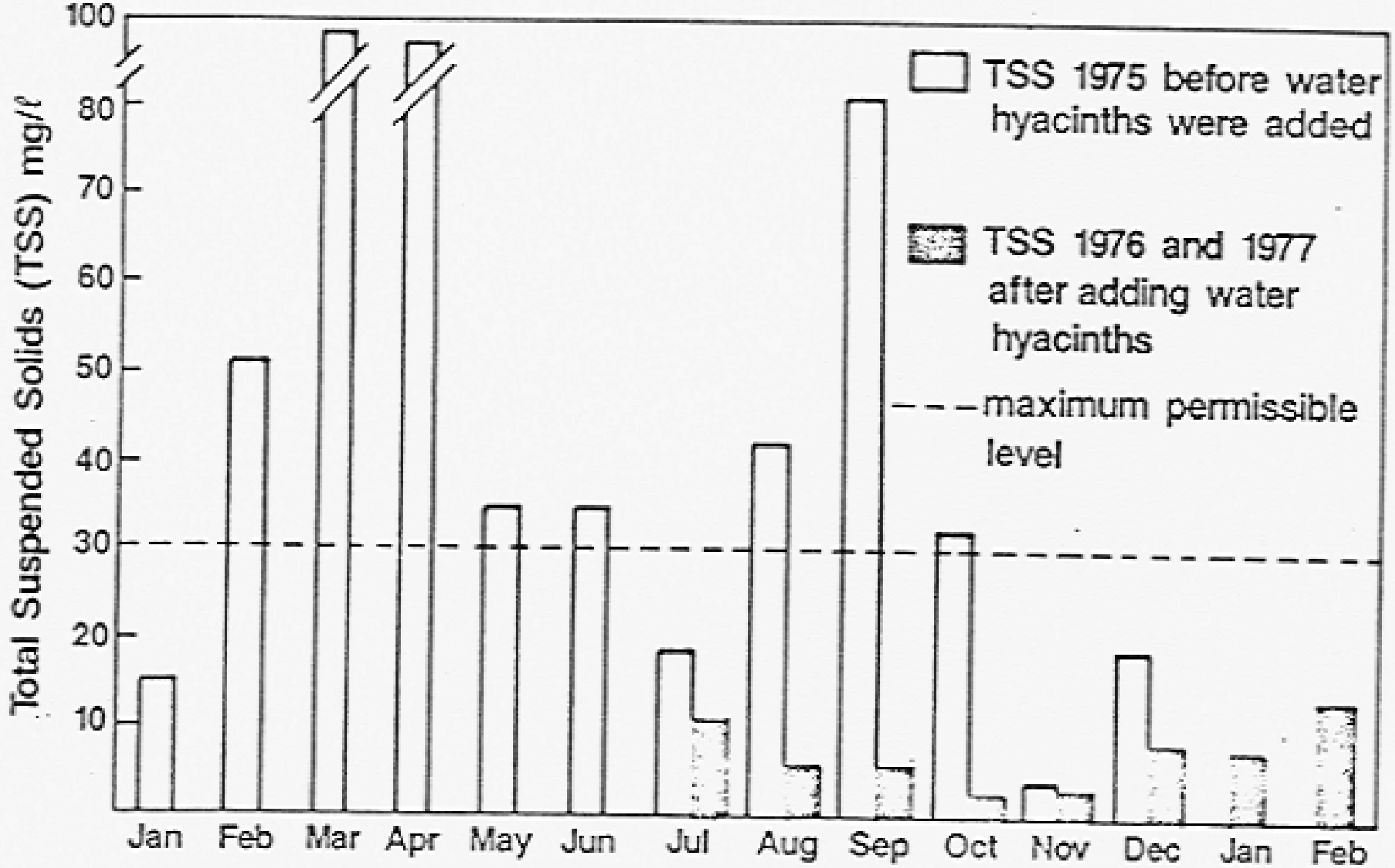
A 0.28 hectare (0.7 acre) surface area lagoon containing a total volume of 6,800 m^3 (1.5 million gallons) was constructed to receive the effluent from a secondary aerated lagoon. The original lagoons plus the water hyacinth lagoon are shown in Figure 3.

Data was collected for one year at Oranne Grove. The water hyacinth



Note: 1983 BOD_5 Effluent Av. 6 mg/ℓ/mo

Figure 1. Effluent Averages for NSTL Lagoon No. 1 BOD_5 Loading of 22 lb/ac/day.



Note: 1983 TSS Effluent Av. 6 mg/ℓ/mo

Figure 2. Effluent Averages for NSTL Lagoon No. 1.

TABLE 1. COMPARATIVE EFFICIENCIES OF THE THREE HARVESTERS USED TO HARVEST WATER HYACINTHS FROM WASTEWATER LAGOONS.

HARVESTER	AV. % TIME HARVESTERS LOADED WITH PLANTS	SURFACE AREA HARVESTED PER HOUR (m^2/hr)		MASS HARVESTED PER HOUR (t/hr)[a]	
		MAX. POSSIBLE	AVERAGE	MAX. POSSIBLE	AVERAGE
Conveyor-chopper	25	414	104	9.1	2.3
Single conveyor	25	1,670	418	36.7	9.2
Modified clamshell bucket	75	558	418	12.3	9.2

[a]Based on an average standing crop of 220 t/ha.

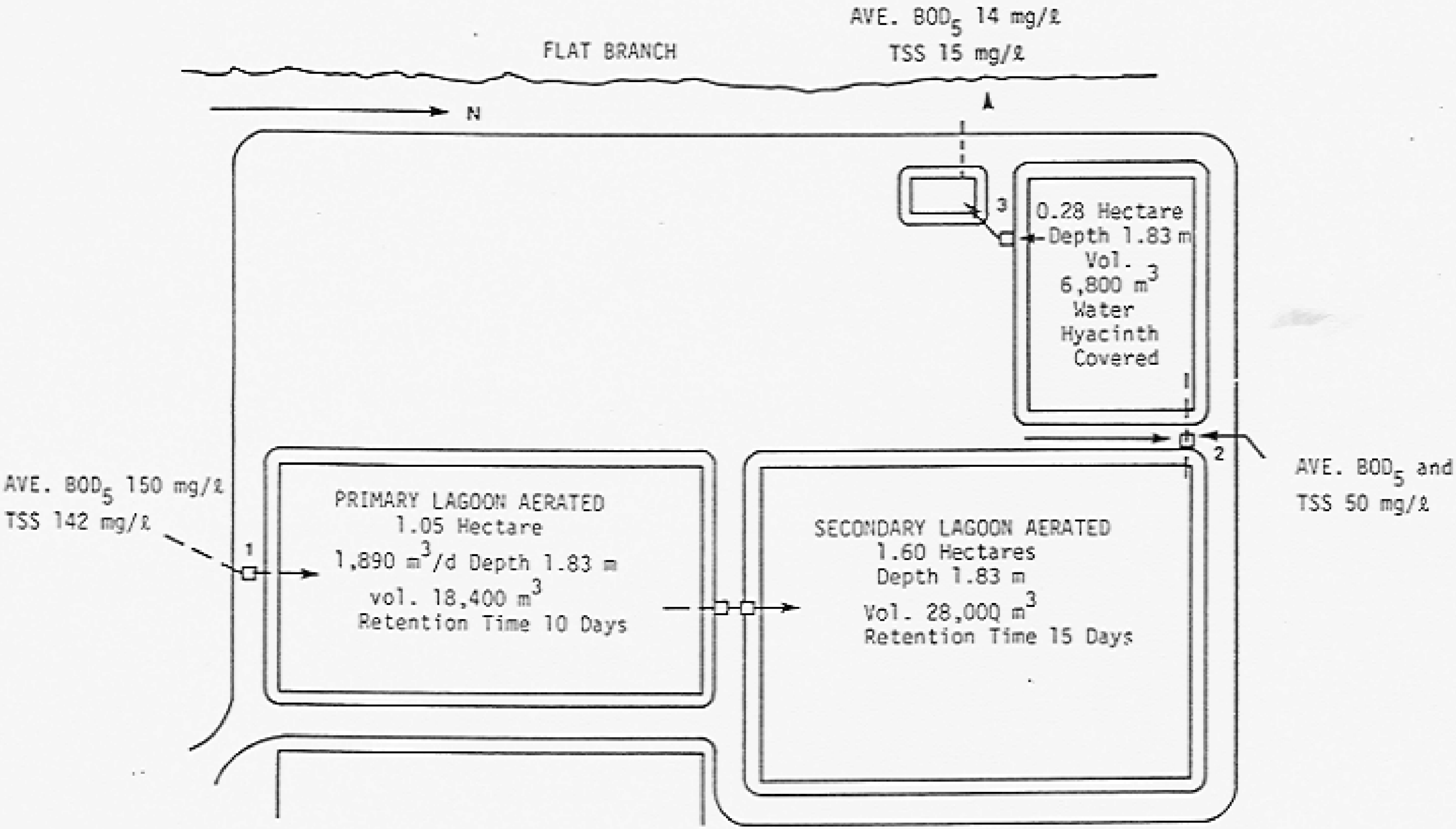


Figure 3. Orange Grove Sewage Layout.

lagoon reduced the monthly average TSS entering from 50 mg/ℓ to 15 mg/ℓ, and the BOD_5 from 50 mg/ℓ to 14 mg/ℓ. The average detention time in the water hyacinth lagoon was 5 days. Even when the detention time was as low as 3 days, the BOD_5 and TSS concentrations in the effluent leaving the water hyacinth lagoon was well below secondary standards of 30 mg/ℓ (16).

In 1979 a joint project involving NSTL, EPA and the Reedy Creek Improvement District (Disney World at Orlando, Florida) was initiated to evaluate the use of water hyacinths for treating primary effluent from the wastewater reclamation plant at Disney World. The wastewater was pumped from a primary clarifier with a 2 hour detention time. The average BOD_5 and TSS leaving the clarifier were 150 and 80 mg/ℓ, respectively. Channels, 8.84 m W x 0.61 m D x 109.73 m L, were constructed to contain the water hyacinths. A detention time of approximately 5 days was maintained. After 5 days in the water hyacinth channels, both the BOD_5 and TSS had been reduced to 20 mg/ℓ, see Table 2. This system has been in operation successfully for 5 years. Present emphasis has now shifted to biomass production for energy (6).

In 1978 a water hyacinth advanced wastewater treatment system was designed for the Coral Springs Improvement District at Coral Springs, Florida to treat 378.5 m^3/d (100,000 gal/d) of secondary effluent from an activated sludge wastewater treatment plant. The system consists of a series of 5 ponds with total water surface area of 0.50 ha (1.25 ac), and an average water depth of 0.38 m (1.25 ft). The total detention time for all 5 ponds was 6 days. In this case, the water quality parameters of primary concern were total nitrogen and phosphorus. Total nitrogen levels into the ponds were reduced by 91% from 10.12 mg/ℓ to o.94 mg/ℓ.

TABLE 2. PRIMARY EFFLUENT FROM THE DISNEY WORLD WASTEWATER RECLAMATION PLANT IN FLORIDA BEFORE AND AFTER TREATMENT WITH WATER HYACINTH. WATER HYACINTH CHANNELS MEASURED 109.73 m (360 ft) L x 8.84 m (29 ft) W x 0.61 m (2 ft) D.

PARAMETER	Conc., mg/ℓ	
	INITIAL	FINAL
BOD_5	150	20
TSS	80	20

Total phosphorus concentrations were reduced by 38% from 6.12 mg/ℓ to 3.77 mg/ℓ which indicates that nutrient uptake by the water hyacinth was nitrogen limited. During several months of the year there was a 50% reduction in volume from influent to effluent due to high evapotranspiration rates (12). If the nitrogen and phosphorus concentrations were adjusted for water loss, the effluent phosphorus concentration would have been approximately 1 mg/ℓ level as required for advanced wastewater treatment. The total nitrogen was well below the 3 mg/ℓ level required.

One of the most advanced aquaculture wastewater treatment systems in the United States is located in San Diego, California. The present system which went into operation in July 1984 is designed to convert raw sewage into a treated effluent acceptable for another water treatment facility presently being designed which will further upgrade it to potable water quality. The system outlined in Figure 4 will comparatively evaluate a sedimentation tank and rotary disc filter for primary treatment during the initial testing. The most cost effective and efficient system will be chosen for the long range project. For secondary treatment, three systems are being compared. The candidate systems -- a pulsating sand filter, a high surface area anaerobic filter and hybrid rock/reed filter -- are all operating in parallel. The most cost effective system which can meet the requirements will be used in the more complete program. Water hyacinths are also included in the advanced wastewater treatment processes.

The potable water processing facility presently being designed will include reverse osmosis (RO) membrane filtration to reduce the high dissolved solids level presently in the San Diego domestic sewage. Pre- and post-filtration will also be used with the RO membrane filter.

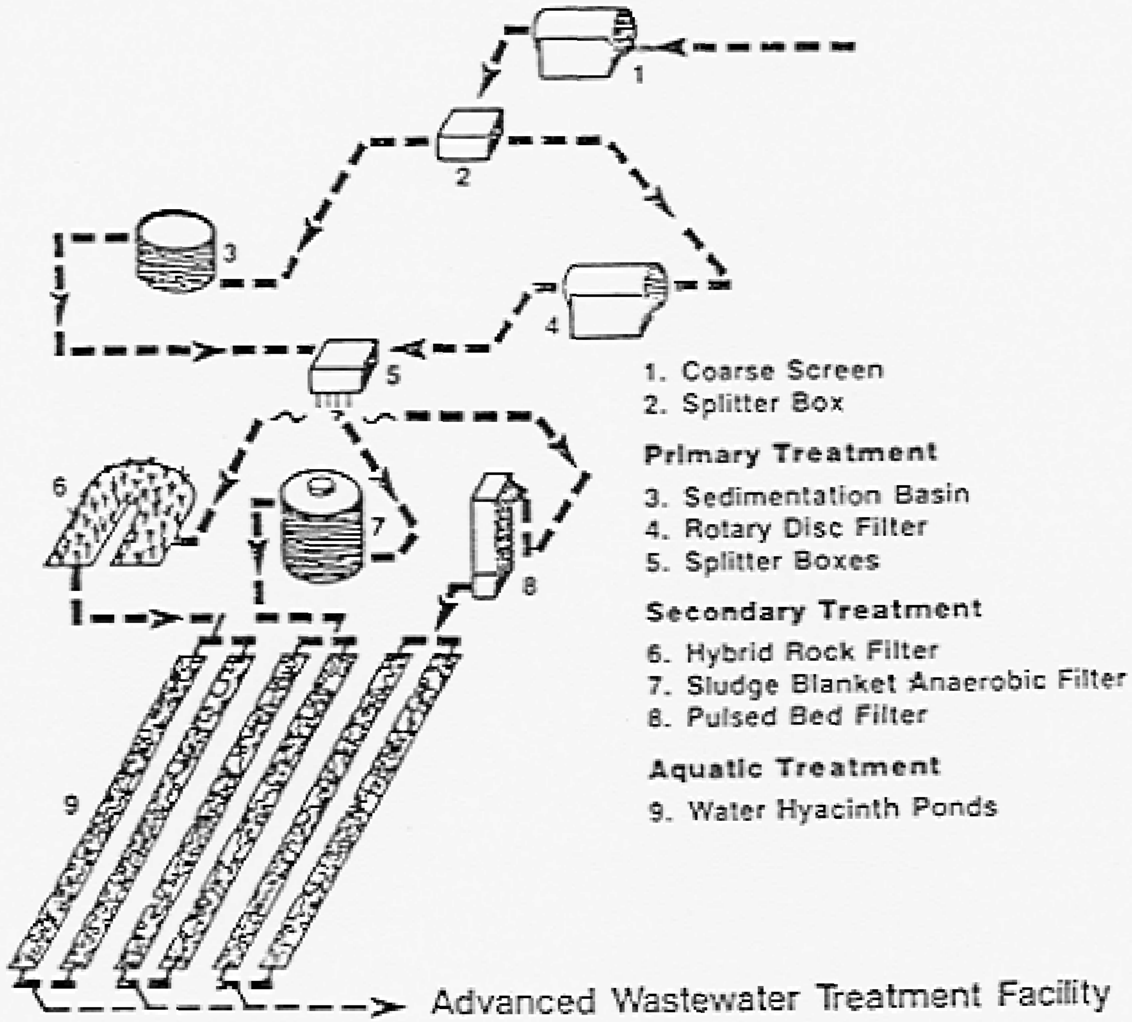


Figure 4. Aquatic Wastewater Treatment Pilot Plant San Diego, California.

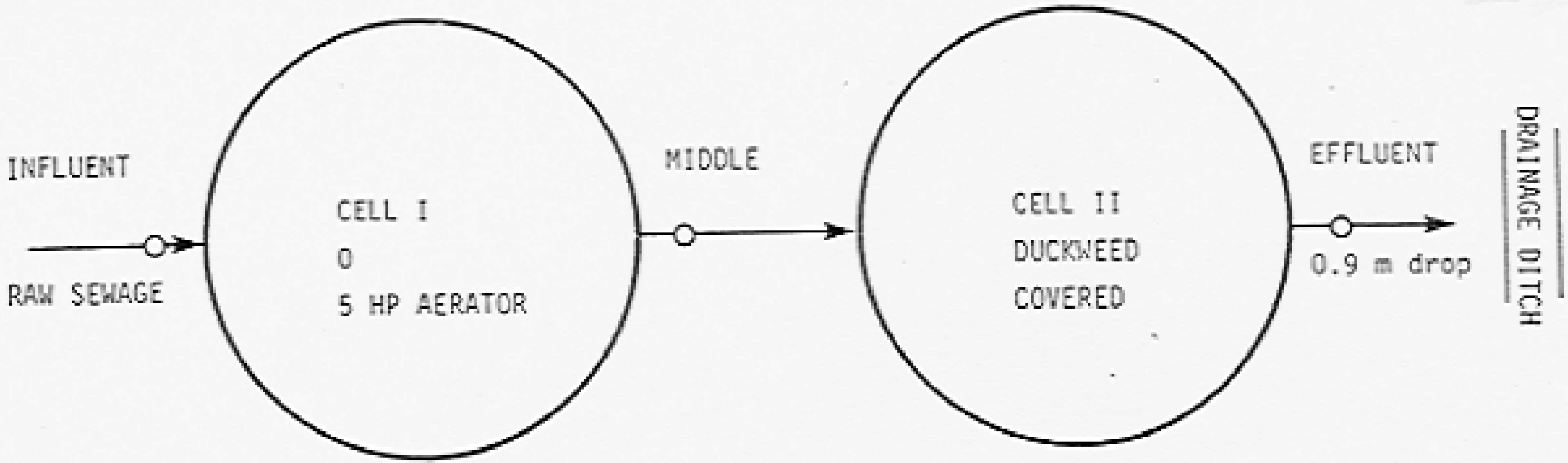
DUCKWEED SYSTEMS

Duckweed (*Lemna* sp., *Spirodela* sp. and *Wolffia* sp.) has been investigated less extensively than water hyacinths for use in wastewater treatment. However, this plant has a much wider geographic range in the United States than water hyacinths because it vegetates at temperatures above 1° to 3° C which makes it more suitable for temperate climates. This small floating plant should be relatively easy to harvest using a continuous belt skimmer similar to those used for removing oil from water surfaces. Because these plants are so small, wind and wave action prevent the maintenance of a continuous mat of plants on large lakes without floating barriers. A continuous mat of duckweed cover will prevent algal growth in wastewater and eliminate the exchange of oxygen between the atmosphere and water, thereby creating anaerobic conditions. This mat will also prevent mosquito production which sometimes causes problems with water hyacinth systems that become anaerobic (1, 5, 11).

In May 1979, NSTL assisted Cedar Lake Development in North Biloxi, Mississippi in evaluating a two cell lagoon wastewater treatment system which had become infested with a mixed duckweed culture of *Lemna*, *Spirodela* and *Wolffia*. During the one year study period, *Wolffia* was the dominant genus. Data from this system is shown in Figure 5 and Table 3.

MINERAL, PROTEIN AND FIBER COMPOSITION OF WATER HYACINTHS AND DUCKWEED

The protein, mineral and fiber content of water hyacinth and duckweed is shown in Tables 4-6. Plants harvested from domestic wastewater, free of toxic metals, are a potential source of animal feed and fertilizer due



DIMENSIONS	CELL I	CELL II
Surface area, ha	0.083	0.075
Depth, m	2.4	1.5
Detention time, d	36	21

FIGURE 5. Diagram of Cedar Lake Development Domestic Sewage Lagoon System.

TABLE 3. MONTHLY MEAN TOTAL SUSPENDED SOLIDS (TSS) AND 5-DAY BIOCHEMICAL OXYGEN DEMAND (BOD_5) OF SAMPLING SITES AT THE CEDAR LAKE DEVELOPMENT WASTEWATER TREATMENT SYSTEM.

	MEAN CONCENTRATION, mg/ℓ					
	BOD_5			TSS		
MONTH	INFLUENT	MIDDLE	EFFLUENT	INFLUENT	MIDDLE	EFFLUENT
May, 1979	201	64	20	178	225	10
June	213	64	28	194	172	9
July	142	33	13	224	98	12
August	160	13	10	291	74	8
September	173	20	17	246	132	22
October	171	15	8	173	96	19
November	264	29	10	159	63	11
December	280	27	15	186	66	15
January, 1980	115	28	15	127	67	21
February	153	27	14	150	63	33
March	180	39	24	203	50	29
April	103	13	11	89	24	29
Yearly Mean	180	31	15	185	94	18

TABLE 4. PROTEIN FROM WATER HYACINTHS AND DUCKWEEDS (ESSENTIAL AMINO ACIDS).

CRUDE* PROTEIN	CONTENT, g/100g (CRUDE PROTEIN) ISO-LEUCINE	LEUCINE	LYSINE	METH-IONINE	PHENYL-ALANINE	THRE-ONINE	TRYPTO-PHANE	TYROSINE	VALINE
Fao ref. pattern	4.20	4.80	4.20	2.20	2.80	2.80	1.40	2.80	4.20
57.8[1]	4.92	9.20	6.60	2.06	6.10	4.99	1.50	4.67	5.84
31.3[2]	4.09	8.68	5.96	1.47	5.70	4.56	1.04	3.55	5.03
39.5[3]	4.64	8.89	6.44	2.16	5.69	4.61	2.10	3.53	5.83

[1] Protein Extracted From Green Water Hyacinth Leaves

[2] Protein From Dried Water Hyacinth Leaves

[3] Protein From Dried Duckweeds *(Spirodela and Lemna* sp.)

*Percent of Dry Weight

TABLE 5. COMPOSITION OF WHOLE PLANTS FROM DOMESTIC SEWAGE LAGOON

PLANT	%, DRY WEIGHT						
	CRUDE PROTEIN	FAT	CALCIUM	POTASSIUM	SULFUR	KJELDAHL NITROGEN	PHOSPHORUS
DUCKWEED	39.5	3.40	1.00	2.00	0.80	6.32	0.85
WATER HYACINTH	23.4	2.20	1.50	4.00	0.40	3.74	0.85

TABLE 6. CELLULOSE, HEMICELLULOSE, AND LIGNIN ANALYSES.

PLANT	% DRY WEIGHT		
	CELLULOSE	HEMICELLULOSE	LIGNIN
WATER HYACINTH	21.5	33.9	6.01
DUCKWEED	10.0	21.7	2.72

to high crude protein, phosphorus and potassium content. Plant biomass can also be converted into energy in the form of methane (29) and the undigested residue used as a fertilizer or soil conditioner.

HYBRID MICROBIAL ROCK/REED FILTER WASTEWATER TREATMENT PROCESS

Although floating aquatic plants such as the water hyacinth have proven to be cost-effective means of treating both domestic sewage and dilute chemical wastewater at NSTL over the past 8 years, their use in colder climates or with high waste concentrations is not practical. In an effort to overcome the limitations of the water hyacinth wastewater treatment system, a more versatile hybrid system using cold tolerant plants combined with a microbial filter has been developed at NSTL (15, 24, 25, 26, 27). The process which has demonstrated the greatest potential to date incorporates the common reed *(Phragmites communis)*, a cold tolerant rooted aquatic plant, into a microbial rock filter bed. This filter bed can be used to treat various wastewaters as shown in Figure 6.

Nitrogen, BOD_5 and TSS can be readily removed from domestic wastewater using relatively short detention times (27). The ability of a reed/rock filter, a rock filter alone and a water hyacinth system to remove low levels of organics from river water is demonstrated in Table 7. This data was obtained from a continuous flow system at NSTL that is part of an experimental system to remove toxic chemicals from Mississippi River water before being processed into potable water for the City of New Orleans.

In 1981 an aerated package treatment system at NSTL's South Reception Center was replaced with a septic tank and reed/rock filter system (Figure 7). The system consists of a 3.8 m^3 (1,000 gal) septic tank in series with a reed/rock filter.

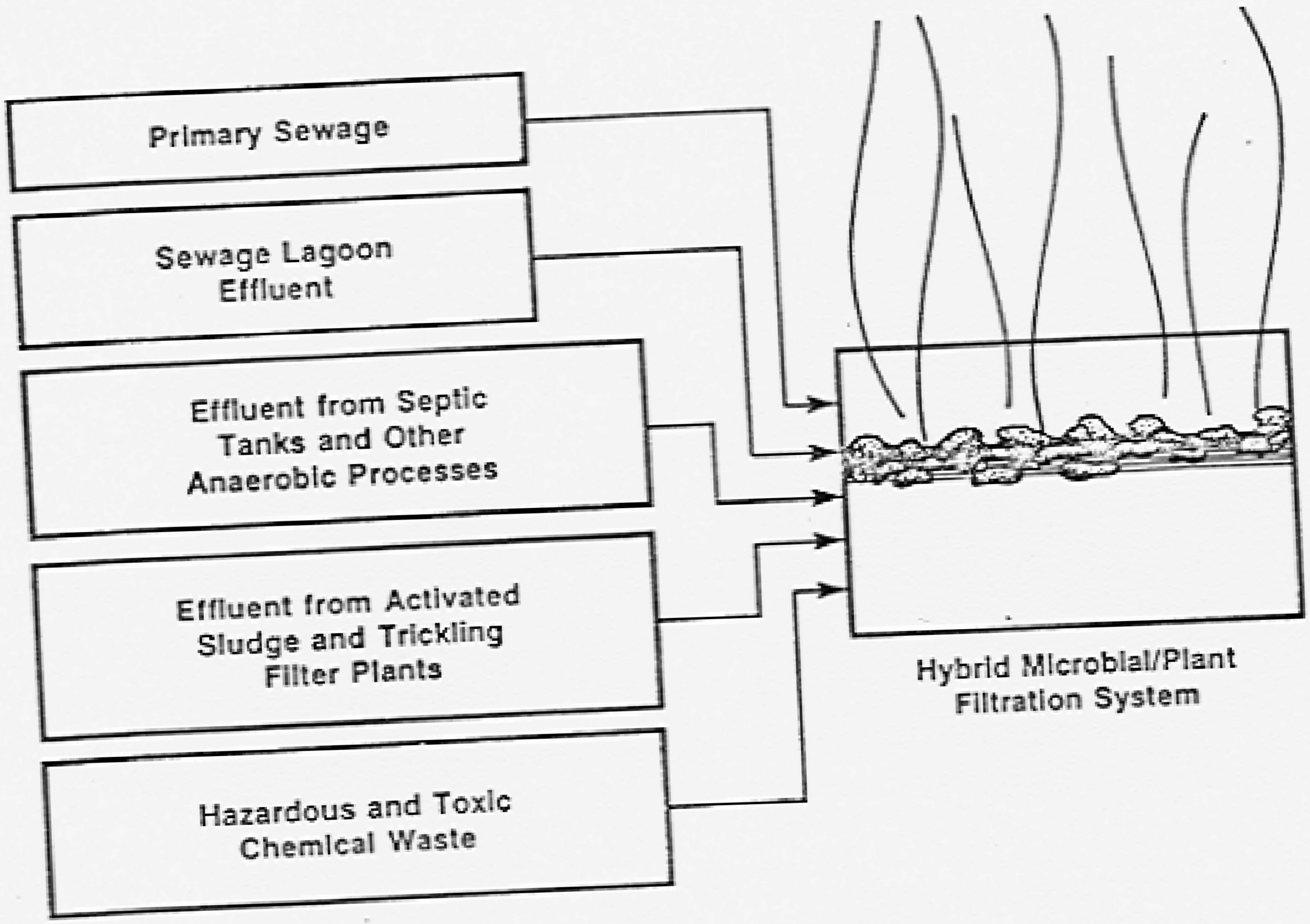


Figure 6. A Microbial Reed/Rock Filtration System for Treating Hazardous and Toxic Chemical Waste and Domestic Sewage After Sludge Removal.

TABLE 7. CONCENTRATIONS OF ORGANIC CHEMICALS IN RIVER WATER BEFORE AND AFTER TREATMENT WITH WATER HYACINTH *(Eichhornia crassipes)*, OR ROCK FILTERS WITH AND WITHOUT REED *(Phragmites communis)*. RIVER WATER CONTINUOUSLY FLOWED THROUGH THESE FILERS WITH A 24-HOUR CONTACT TIME.

	MONTHLY AVERAGE CONCENTRATION, ppb			
Organic	Before Treatment	Reed/Rock Filter	Rock Filter	Water Hyacinth
Naphthalene	4.00	<0.10	<0.10	0.71
Biphenyl	5.27	<0.02	<0.02	<0.02
Dimethyl Phthalate	7.48	<0.18	<0.18	0.32
P-Nitrotoluene	10.58	<0.31	<0.31	3.52
Ethyl Benzene	2.80	0.17	0.18	0.15
Toluene	2.64	0.22	0.21	0.23
P-Xylene	1.06	<0.10	<0.10	0.15
Benzene	3.53	0.45	0.37	0.18

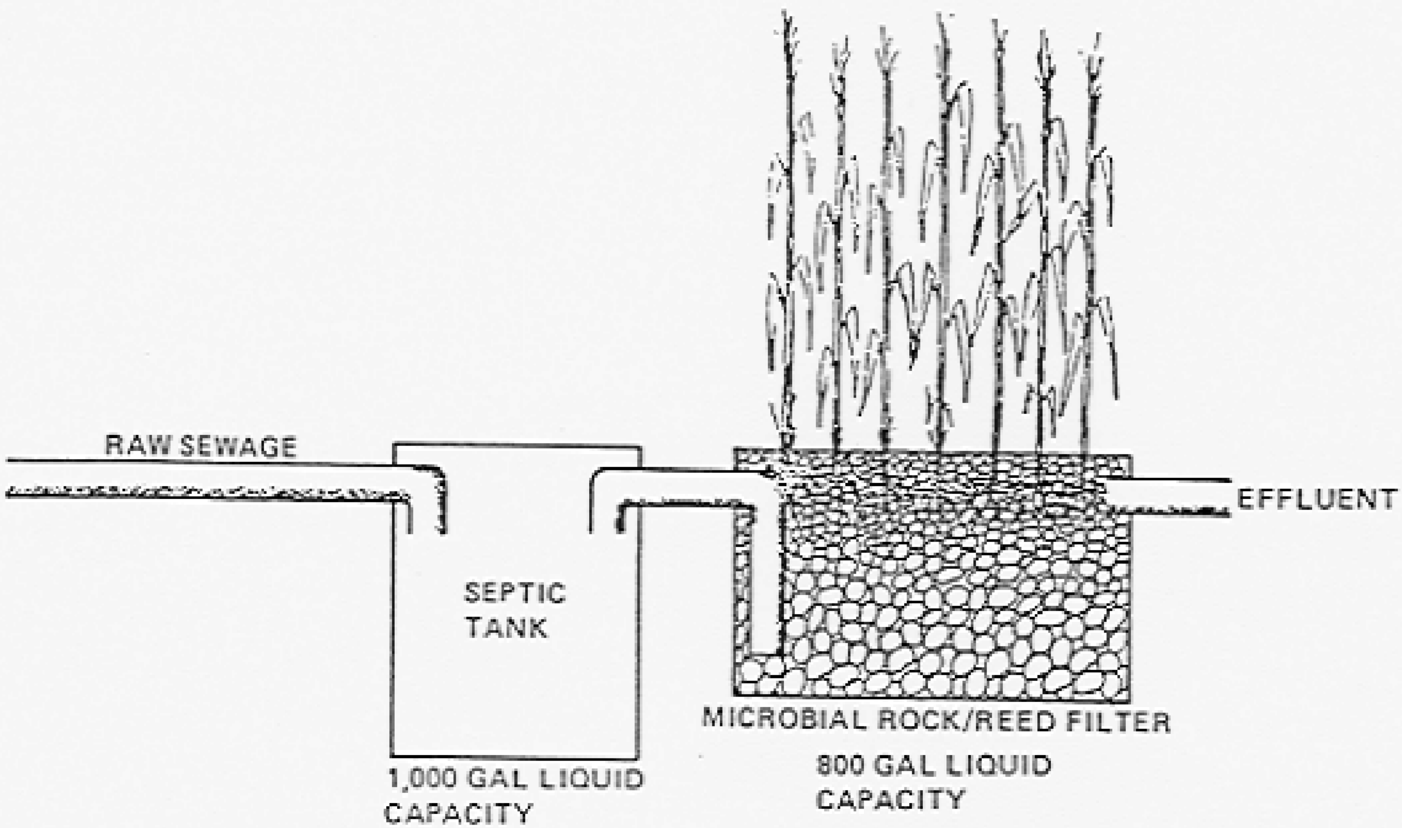


Figure 7. NSTL South Gate Wastewater Treatment System.

The filter bed consists of a metal trough measuring 2.74 m L x 1.22 m W x 1.83 m D (9 ft L x 4 ft W x 6 ft D). The trough was filled almost to the top with rocks (2.5-7.6 cm in diameter). The top 15 cm was filled with pea gravel (0.25-1.27 cm in diameter) and planted with reeds *(Phragmites communis)*. The resulting filter bed has an estimated void volume of 3.0 m^3 (800 gal). The system receives approximately 1.9 m^3 (500 gal) of raw sewage per day from 15-18 office workers.

In 1982 the aerated package plant at the NSTL North Reception Center was also replaced with a 3.8 m^3 (1,000 gal) septic tank and a similar rock filter bed having an estimated void volume of 1.9 m^3 (500 gal). The filter was covered with plastic and maintained free of reeds. The effluent from the anaerobic filter flows through a third component consisting of 6.1 m (20 ft) of 25.4 cm (10") diameter plastic pipe containing rocks (2.5-7.6 cm in diameter). Holes were cut out of the top of the pipe for adding reeds (Figure 8). This system receives approximately 1.9 m^3 (500 gal) daily of wastewater from 15 office workers. Results from these systems are shown in Tables 8 and 9.

A combination of water hyacinth, rooted plants and microorganisms is also a potential process for cleaning-up hazardous and toxic waste sites where both soil and water are contaminated with toxic heavy metals, possibly radioactive waste and organic chemicals.

SUMMARY AND RECOMMENDATIONS

1. The use of water hyacinth ponds to upgrade effluent from waste stabilization lagoons and other wastewater treatment facilities to secondary standards has been sufficiently developed to make it a viable

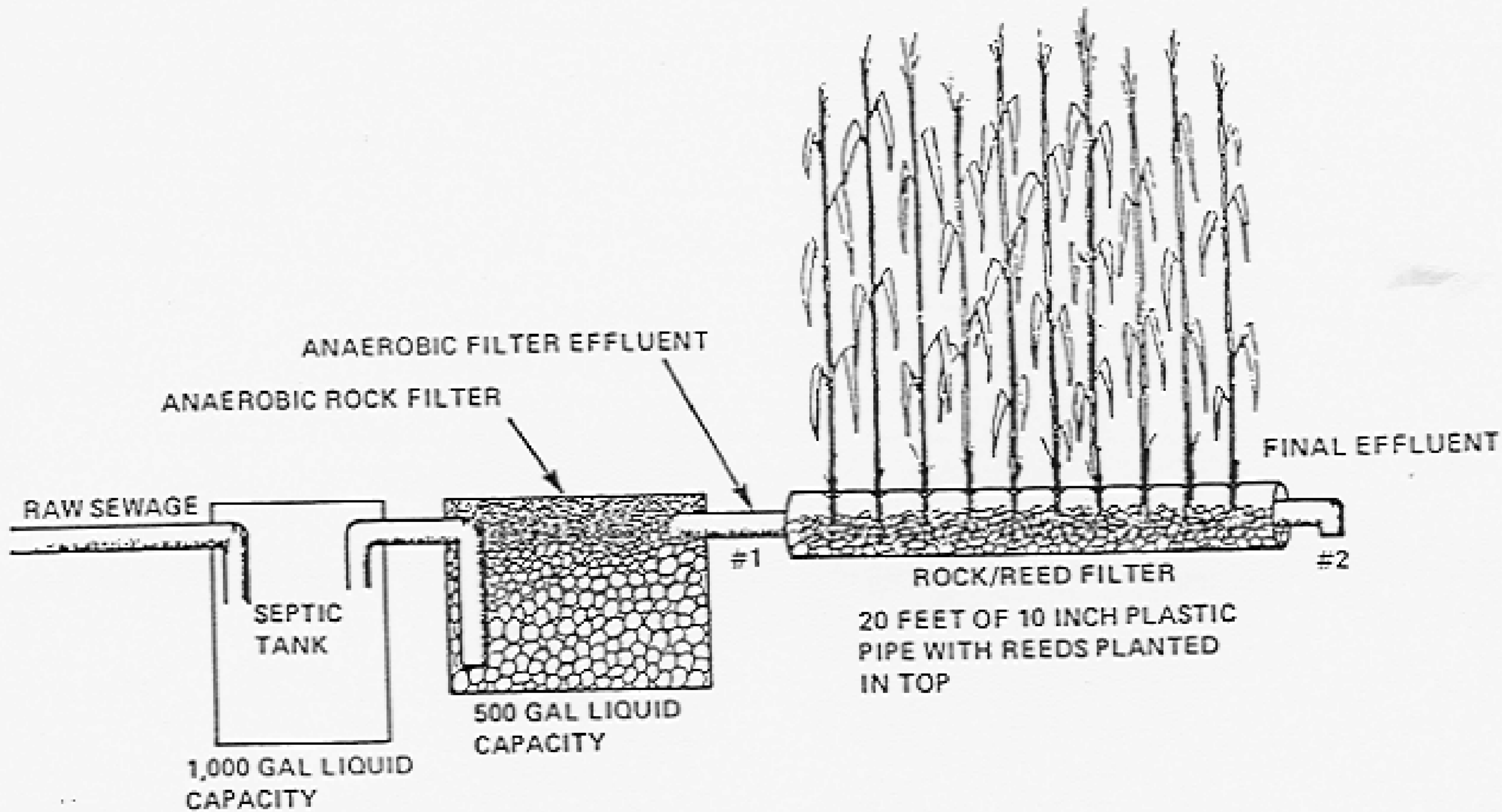


Figure 8. NSTL North Gate Wastewater Treatment System.

TABLE 8. NSTL NORTH GATE WASTEWATER EFFLUENT QUALITY FROM REED/ROCK FILTER SYSTEM.

	MONTHLY AVERAGE CONCENTRATION, mg/ℓ							
	BOD_5		TSS		DO		pH[1]	
MONTH	#1	#2	#1	#2	#1	#2	#1	#2
August 1982	34	7.4	10.5	0.5	0.7	2.0	7.5	7.7
September	27	9.0	9.0	0.6	0.8	2.8	7.5	7.4
October	27	6.5	9.3	2.0	0.8	2.3	7.5	7.6
November	42	9.0	8.8	2.0	1.0	2.2	7.6	7.7
December	46	9.4	21.6	4.0	1.2	3.1	7.6	7.6
January 1983	51	15.7	16.0	10.0	0.9	3.5	7.4	7.6
February	42	11.7	32.0	24.0	1.0	4.7	7.3	7.5
March	56	24.0	42.7	8.0	1.5	3.5	7.1	7.3
April	47	16.0	16.0	0.7	0.8	3.2	6.9	7.2
May	50	25.0	36.8	0.0	1.1	2.6	6.9	7.1
June	36	16.2	36.8	7.2	0.8	2.4	7.0	7.3
July	34	7.3	39.0	4.0	0.9	2.6	7.1	7.4

#1 = Anaerobic Rock Filter Effluent

#2 = Reed/Rock Filter Effluent

[1] Standard units

TABLE 9. NSTL SOUTH GATE WASTEWATER EFFLUENT QUALITY FROM REED/ROCK FILTER SYSTEM.

MONTH	MONTHLY AVERAGE CONCENTRATION, mg/ℓ			
	BOD_5	TSS	DO	pH[1]
August 1981	11	6	5.0	7.4
September	13	2	5.3	7.4
October	15	4	5.7	7.5
November	21	4	6.0	7.5
December	20	7	5.1	7.4
January 1982	18	1	5.0	7.6
February	21	12	5.0	7.4
March	18	17	5.5	7.7
April	23	5	5.0	7.6
May	12	5	5.0	7.8
June	16	15	3.1	7.8
July	18	8	3.0	7.7

EPA Permit Levels of 30 mg/ℓ or less of BOD_5 and TSS Required

[1]Standard units

process in warm climates.

2. The use of water hyacinth ponds to upgrade seconary effluent to advanced waste treatment standards in tropical climates is also a viable process if mass balance is taken under consideration due to the mineral concentration caused by water loss through evapotranspiration. Additional phosphorus removal may be necessary.

3. The use of duckweed ponds to upgrade effluent from stabilization lagoons to secondary standards is a viable process when minimal aeration is available to increase dissolved oxygen in the effluent. Duckweed have advantages over the water hyacinth in that greenhouse covers during the winter months should not be required in temperate and semitropical climates such as found in most of the United States.

4. Past experience indicates that a 5 day detention time is desirable for water hyacinth and duckweed systems receiving algal-ladden influent.

5. The hybrid reed/rock filter system has demonstrated the ability to treat wastewater from various sources as shown in Figure 6. A detention time of 24 hours is desired with primary wastewater. A detention time of 6-12 hours is sufficient for upgrading secondary facilities.

The hybrid filter system is capable of handling shock loading and can receive anaerobic effluent and clarify it to odor-free effluent if sufficient detention time is incorporated into the filter.

6. Solids must be removed from raw sewage before using the rock filter to prevent potential clogging problems. The size of rocks used in the front of the filter is critical especially if a high algal lagoon effluent is to be treated.

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